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Energy-Conserving Characteristics of Common Building Materials and Methods

Projects supported in part by the Alberta/Canada
Energy Resources Research Fund

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Cover Photo: At the Alberta Home Heating Research Facility near Edmonton, research studies carried out under carefully controlled conditions showed how home heating bills can be affected when changes are made to certain components of a building. One such study involved the use of experimental shutters (shown here) on south-facing windows.

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Disclaimer

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Foreword

Since 1976, numerous projects have been initiated in Alberta by industry and by academic research institutions which are aimed at better utilization of Alberta's energy resources.

These research, development and demonstration efforts were funded by the Alberta/Canada Energy Resources Research Fund (A/CERRF), which was established as a result of the 1974 agreement on oil prices between the federal government and the producing provinces.

Responsibility for applying and administering the fund rests with the A/CERRF Committee, made up of senior Alberta and federal government officials.

A/CERRF program priorities have focused on coal, energy conservation and renewable energy and conventional energy resources. Administration for the program is provided by staff within the Scientific and Engineering Services and Research Division of Alberta Energy.

In order to make research results available to industry and others who can use the information, highlights of studies are reported in a series of technology transfer booklets. For more information about other publications in the series, please refer to page 14.

Energy-Conserving Characteristics of Common Building Materials and Methods

Most of the available information about energy conservation techniques that can be used in buildings is either of an empirical nature or results from fundamental investigations undertaken in climates that are not as severe as Alberta's. In empirical studies, modifications are made to homes or commercial buildings and then measurements are made of such variables as fuel consumption, comfort level and air exchange rates to see how they are affected.

While knowledge acquired in this manner is important and valuable, the information is difficult to quantify in a way that allows accurate assessment of the contributions made by individual building components, nor does it provide much accuracy in developing computer models of heat transfer mechanisms operating within various structures.

Alternatively, simple mathematical models of heat transfer mechanisms, developed by the American Society of Heating, Refrigeration and Air Conditioning Engineers (ASHRAE), have been used by building designers for years, but their predictive capabilities are somewhat limited under certain conditions.

To help overcome these deficiencies, A/CERRF funded several studies which were designed to be more fundamental in nature and would provide a better theoretical basis for certain energy conservation concepts. In particular, these investigations have pinpointed some energy conservation methods that are practical in Alberta.

Home Heating Research

In 1979, the Alberta Home Heating Research Facility was constructed to provide a site for research and development studies aimed at optimizing residential insulation and heating strategies appropriate for a northern climate. The facility consists of six, single-storey housing modules, each measuring 6.8 x 7.4 metres (22 x 24 feet) in plan with full concrete basements.

These uninhabited modules are located at the University of Alberta Farm near Ellerslie (south of Edmonton) in a single east-west row. All of the buildings were framed using conventional 50 mm x 100 mm (two in. by four in.) studs, 406 mm (16 in.) on centre with a gable roof on elevated roof trusses which can accommodate up to 0.85 metre (33 in.) of insulation. Each module has the same exterior and roofing finish, one door and the same interior finish. Incorporated into the structure of each module are different features which allow evaluation of the energy-conserving characteristics of individual components, as well as direct comparisons of performance between or among modules. This is made possible by a computer-controlled data acquisition system.

The basic research strategy involved the collection of data from each module on a continuous basis, and using the gathered data to refine several existing computer simulations of the heat transfer mechanisms that occur in residential buildings. The approach also allowed researchers to identify some energy conservation options that are cost effective in the Edmonton-area climate.

The Alberta Home Heating Research Facility. Modules are numbered one to six, left to right.

Module Characteristics

The modules were built in such a manner that, collectively, they represent the wide range of insulation levels found in Alberta homes.

Module One, the "short-term" unit, was built with large removable panels in each wall to allow in situ testing of alternative wall or window configurations. In later years, the walls of Module One were replaced by double wythe masonry walls.

Module Two, the "standard" module, was built to pre-1970 construction standards with minimal insulation. Between 1979 and 1982, Module Two was used as a control or reference for the other modules. After 1982, Module Five served this purpose.

Module Three, the "conservation" unit, was given sufficient insulation to make it consistent with "superinsulated" homes built during the late 1970s.

Module Four, called the "passive" module, was built with a moderate amount of insulation and a large area of south-facing windows to facilitate studies of passive solar heating.

Modules Five and Six, referred to as the "active liquid" and "active air" modules respectively, were intended to allow assessments of two active solar systems with different working fluids operating under identical conditions. However, only the active air system was installed (the active water system was deemed to be too expensive), and, in 1980, the ceiling insulation level in Module Six was upgraded from RSI 2.1 (R12) to RSI 5.64 (R32).

All modules were heated electrically to permit direct measurement of energy consumption without having to consider furnace efficiencies. Energy was dissipated by a central electric furnace in each unit, and the warm air was distributed throughout each module by way of metal ductwork and a blower. Except in the energy conservation module, each unit was equipped with a single 152 mm (six in.) diameter class B vent to simulate conditions in a residence equipped with a natural gas furnace.

Insulation Levels

	Ceiling		Wall		Basement	
Module	RSI	R	RSI	R	RSI	R
1. Short term	2.11	12	1.76	10	1.76	10*
2. Standard[a]	2.11	12[c]	1.41	8[d]	–	–
3. Conservation	14.08	80	7.04	40	3.52	20**
4. Passive	7.04	40	3.52	20	1.76	10**
5. Active Liquid[a]	2.11	12	1.76	10	1.76	10*
6. Active Air	5.64	32[b]	1.76	10	1.76	10*

* from floor level to 0.6 m (2 ft.) below grade

** full height

[a] in 1982-83, Module Five became the new standard module to allow retrofits of Module Two

[b] initially R12; raised to R32 in 1980

[c] in 1983-84, the ceiling insulation was upgraded to R32 (RSI 5.64)

[d] in 1984-85, the above-grade wall insulation was upgraded to R18 (RSI 3.17)

(Source: *A Study of Residential Housing Envelope Heat Losses*, M.Y. Ackerman, University of Alberta, April 1983)

Data Collection

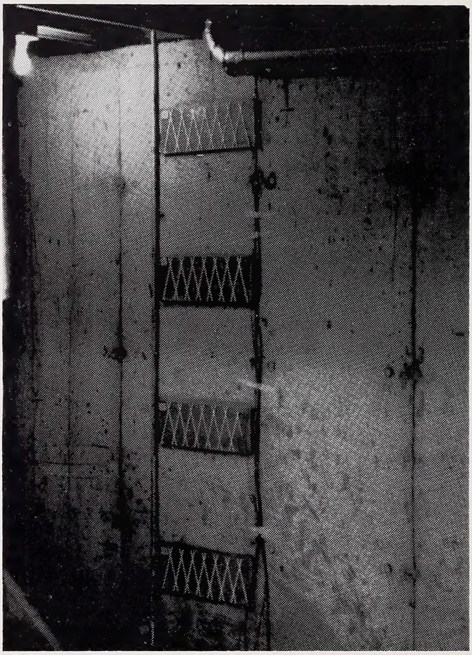
In analyzing the energy performance of a building, it is essential that measurements be made of the room air temperature, the ambient air temperature and the energy input to the structure. While this allows crude assessments of the overall performance, more information is needed to determine the contribution of any building component to the heating load. Additional measurements include: basement and attic air temperature, available solar radiation, wind speed and direction, the air infiltration rate, thermal properties of individual components and ground temperature on a seasonal basis.

A microprocessor-based data logger was used to record these various parameters every day for several years. The data logger, an Analog Devices Macsym II modified with an external multiplexer, monitored temperature at more than 30 locations, as well as radiation at five locations, wind speed and direction from two 10-metre towers, the energy input to each module, and heat flux at more than 40 locations.

While most of these variables could be measured with readily available instruments, it was necessary to design and build heat flux gauges to measure heat flow through various building components. Each transducer consisted of a series of thermocouples on each side of a quarter inch layer of cork, which was sandwiched between two one-eighth inch Plexiglas sheets. Each measured 15.2 cm by 40.6 cm (six in. by 16 in.) and provided an average heat flux reading over a typical section of composite wall.

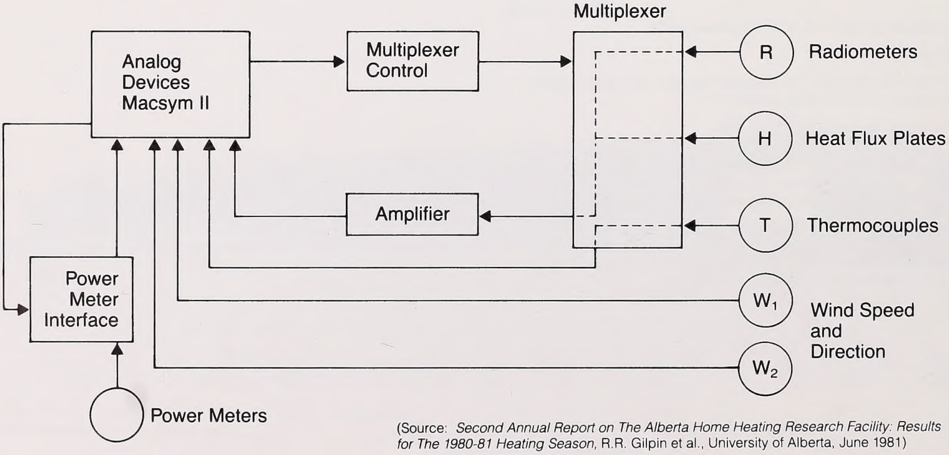
Air infiltration measurements were made by determining the change in concentration over time of sulphur hexafluoride tracer gas.

Once every minute the signals from each sensor and measuring device were scanned and stored by the data logger. At the end of each hour the signals were averaged and stored on magnetic tape. Once a week the infomation was transferred to the mainframe computer at the University of Alberta for subsequent evaluation.



Typical placement of heat flux gauges on basement walls at the Alberta Home Heating Research Facility.

Schematic of Data Acquisition System



(Source: *Second Annual Report on The Alberta Home Heating Research Facility: Results for The 1980-81 Heating Season,* R.R. Gilpin et al., University of Alberta, June 1981)

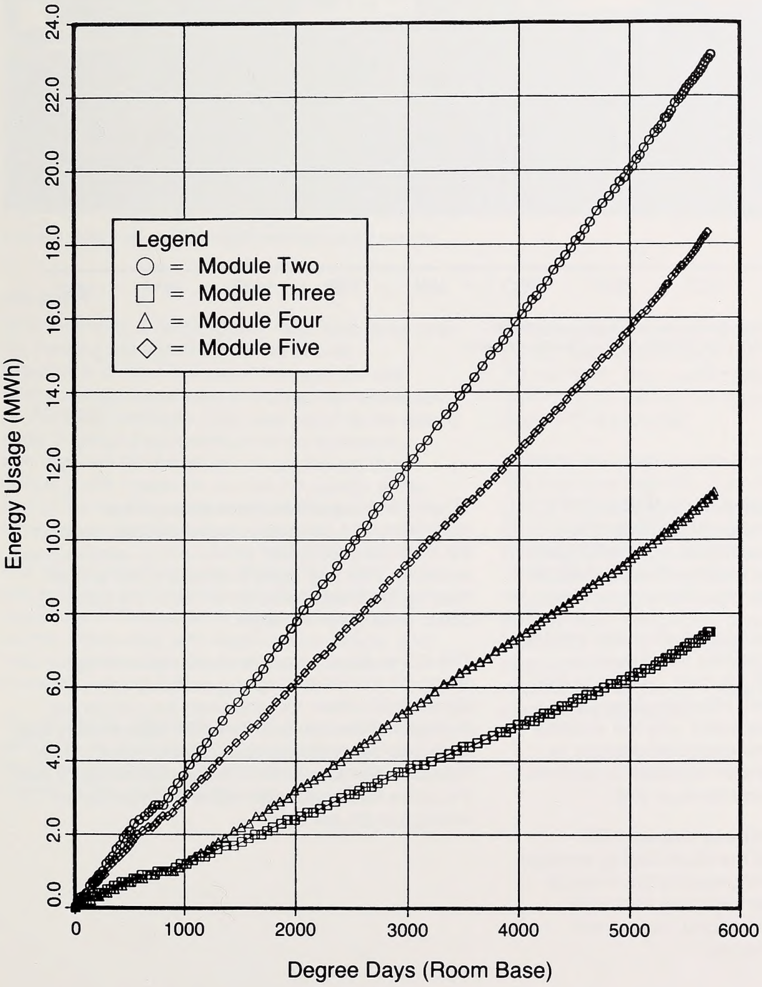
Data Analysis

Beginning with the 1979-80 heating season, the modules were monitored to determine energy usage under a measured set of ambient conditions. This information also provided baseline values that allowed each of the modules to be compared with the standard module, and permitted assessment of the impact of modifications which were made in later years.

Over the heating season, cumulative energy consumption for each module was plotted against cumulative heating degree days (a measure of how cold a location is) based on the indoor-outdoor temperature differential.

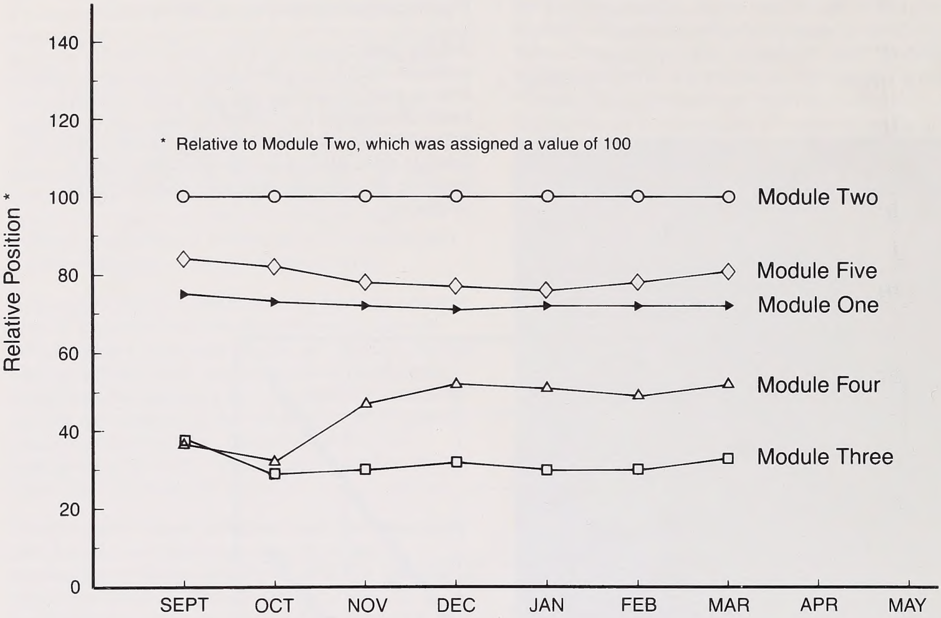
Initially, one objective of the study was to evaluate techniques that were being used at the time to predict energy requirements, and had been developed by ASHRAE. Also, it was expected that data from the test facility could be used to evaluate more sophisticated energy analysis techniques whenever they became available.

Total Energy Usage for Four Test Modules During the 1982-83 Heating Season



(Source: J.D. Dale, Department of Mechanical Engineering, University of Alberta)

Relative Energy Consumption of Modules, 1982-83 Heating Season



(Source: *Fourth Annual Report on The Alberta Home Heating Research Facility: Results of The 1982-83 Heating Season,* M.Y. Ackerman et al., University of Alberta, April 1984)

Observations

Solar Gain

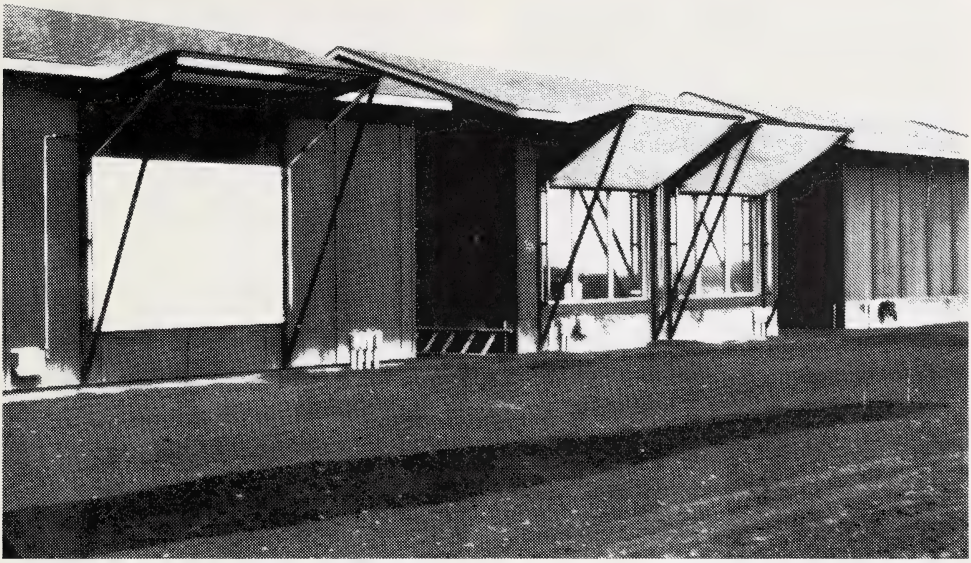
Small, double-pane, south-facing windows in a moderately insulated house in the Edmonton area probably will not provide any net solar gains when averaged over the heating season. If larger windows are used, a net loss of energy is likely.

However, if interior or exterior shutters are used on south-facing windows, heating requirements could be reduced by 20 per cent, assuming the shutters are provided with effective edge seals. Based on measurements made with the shutters locked open or closed for extended periods, a double-pane, sealed window appears to perform like a moderately insulated opaque wall.

When an inside brick wall was placed 1.52 metres (five feet) behind the south-facing windows of Module Four, thereby increasing the mass of the module by seven per cent, day and night energy usage patterns changed, but overall energy usage was unaffected.

Observations such as these allowed the researchers to develop a mathematical model of the heat load reduction produced by passive solar systems. This was used to estimate the annual heating load requirements of houses employing direct solar gain concepts.

The active air solar system collected enough energy in the fall and spring seasons to significantly affect requirements for purchased energy in those periods, but little solar energy was collected during December, January and February. Consequently, energy requirements over the entire heating season were reduced by an average of 25 per cent.



Modules Three (left) and Four (right) showing shutter systems.

Insulation

Measurement of below-grade heat loss rates over the heating season showed the overall resistance of heat flux paths through the soil surrounding a basement is higher than predicted by ASHRAE methods. This was found to be due to a lag in ground temperature when compared with ambient temperature, which means that below-grade losses do not fall off rapidly at the end of the heating season when the air temperature begins to rise again.

The measurement of heat losses from the below-grade portions of walls showed that the amplitude of the variation of heat loss was rapidly attenuated with depth below grade, and heat losses through the floor were essentially constant year-round.

The phase lag between heat flux and ambient temperature was observed to increase with depth below grade, to a maximum of three to four months at the centre of the basement floor.

When a basement wall was insulated to RSI 1.76 (R10), heat loss through the wall was reduced by 70 per cent. This could mean an overall energy saving of 25 per cent in a bungalow insulated to pre-1970 standards.

Houses insulated to present-day levels, as in Module Four, with RSI 7.04 (R40) in the ceiling, RSI 3.52 (R20) in the above-grade walls and RSI 1.76 (R10) in the basement walls, need only half the purchased energy of homes insulated to pre-1970 standards. The superinsulated module required between 33 and 36 per cent of the energy input needed by homes built before 1970. When the ceiling insulation in Module Six was upgraded from RSI 2.11 (R12) to RSI 5.64 (R32), it caused a nine per cent reduction in heating energy requirements.

Air Infiltration

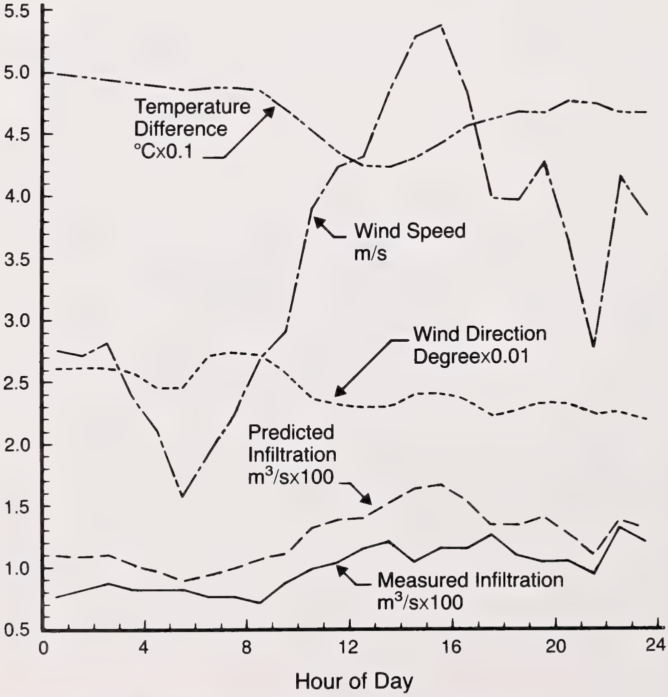
While auxiliary energy requirements of a heated, residential structure are in part due to differences between the ambient and indoor temperatures, the relationship is not linear due to the influence of other factors, in particular air infiltration. Air leakage itself was found to behave in a non-linear manner that is difficult to predict. Rates of air leakage measured in the uninhabited modules using the sulphur hexafluoride decay method were found to be lower than the generally accepted values of 0.5 to 1.0 air changes an hour. This was partly due to the construction characteristics of the modules themselves, but primarily because people seldom opened doors to enter or leave the modules.

Studies showed that even in homes that use present-day levels of insulation, air infiltration can easily become the dominant heat loss factor, accounting for up to 30 per cent in some instances.

Fifty per cent of the air leakage in Module Four, which contained a moderate amount of insulation, was due to the open flue vent. While the module occupies only half the volume of a typical home, significant air leakage through the furnace flue vent can be expected in a normal-size home. Furthermore, when furnaces were operating in one of the modules (during a separate study of furnace efficiency) more air was drawn into the module, causing air infiltration rates to rise by as much as an additional 40 per cent.

In the superinsulated module, even though great care was taken to install the air-vapor barrier, and a flue pipe was not used, air leakage was still 42 per cent of that found in Module Four, which has a flue vent and in which no special precautions were taken when the air-vapor barrier was installed. To the investigators, this demonstrated that removal or blockage of the furnace vent (by, for example, a properly designed vent damper system) can have a major influence on air infiltration rates.

Predicted and Measured Hourly Average Air Infiltration Rates for a Day with South-East Winds — Module Three



(Source: *Final Report on The Alberta Home Heating Research Facility: Results of The 1981-82 Heating Season and Part of The 1982-83 Heating Season to January 1983,* M.Y. Ackerman et al., University of Alberta, February 1983)

Thermal Performance of an Insulated Masonry Structure

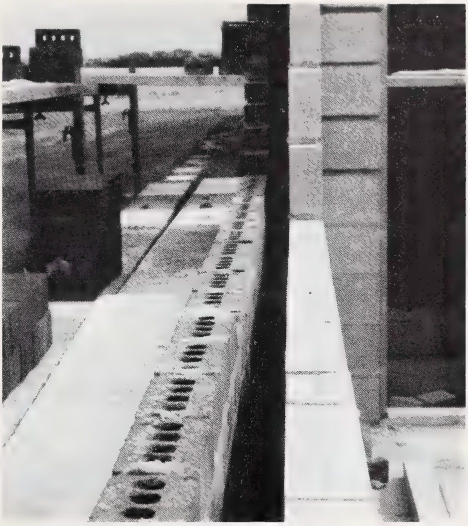
In 1982-83, a two-year project was initiated to study the effect of masonry walls on energy consumption. It was carried out at the Alberta Home Heating Research Facility using the same data acquisition and analysis systems described above. With financial assistance provided by I-XL Industries Ltd., the Alberta Masonry Institute, Consolidated Concrete Limited and Fleck Bros. Limited (as well as A/CERRF), the first step involved covering the above-grade walls of Module One with a brick veneer wall. While it was found this change reduced the measured heat transfer rates through the walls, it had a negligible effect on the overall energy consumption.

The following year, the above-grade wooden walls of Module One were removed and replaced with double wythe, load-bearing masonry walls. The cavity between the exterior brick wall and the interior concrete block wall was filled with foamed-in-place polyurethane (with vermiculite in one-third of the north wall).

When compared with a reference wood-framed unit (Module Five), it was found the "Masonry Module" required 20 per cent less heating energy. This was due, in part, to higher insulation levels in the walls, but also because the air infiltration rate was 40 per cent lower than the wood-framed reference unit.

In measuring heat transfer rates through the interior surface of the cavity wall, it was discovered there was a time lag of from eight to 10 hours between the occurrence of the minimum outdoor temperature and the time when maximum rates of heat transfer occurred. This was due to the large thermal storage capacity of the wall, which resulted in a more evenly balanced heating load throughout the day.

Although the initial, total construction costs are about 10 per cent higher using masonry walls as opposed to conventional wood-frame construction, it is expected energy savings, lower costs for insurance and maintenance and a more attractive appearance will more than compensate for any capital cost increase. Over the long term, masonry homes and wood-frame homes should cost about the same. When the costs of construction and maintenance and home resale values are taken into account, estimates showed the costs of the two types of structures should become virtually identical 10 years after they are built.



Double wythe wall under construction. The space between the walls was filled with polyurethane or vermiculite.

Although A/CERRF funding of these home-heating studies ended in 1986, the facility has been used for investigations on behalf of other clients and is expected to be the source of additional studies for years to come.

Further Reading

Gilpin, R.R., J.D. Dale, T.W. Forest and M.Y. Ackerman. 1980. Construction of the Alberta Home Heating Research Facility and Results for the 1979-1980 Heating Season, University of Alberta.

Gilpin, R.R., T.W. Forest, M.Y. Ackerman, D.G. Wilson, G.W. Sadler, J.D. Dale and M. Zaheeruddin. 1981. Second Annual Report on the Alberta Home Heating Research Facility: Results for the 1980-81 Heating Season, University of Alberta.

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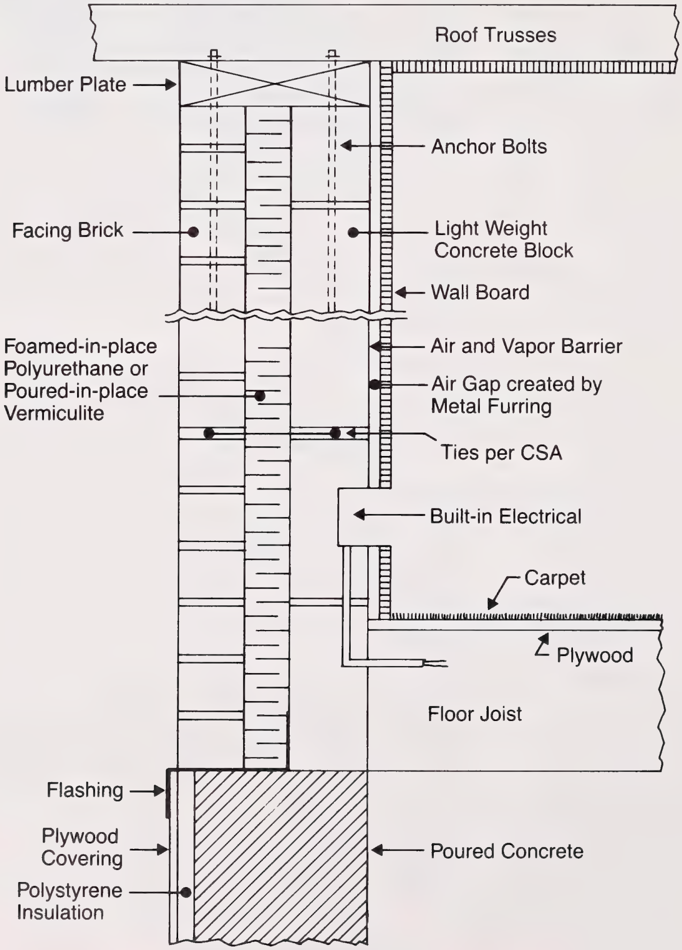
Kostiuk, L.W. and J.D. Dale. 1985. Final Report on the Thermal Performance of an Insulated Masonry Structure, University of Alberta.

Dale, J.D. and L.W. Kostiuk. 1986. Summary Report on the Thermal Performance of an Insulated Masonry Structure, University of Alberta.

Cross-section of Double Wythe Wall



(Source: *Thermal Performance of an Insulated Masonry Structure: Results of The 1983-84 Heating Season*, Kostiuk, L.W. and J.D. Dale, University of Alberta, October 1984)

Computer Analysis of Thermal Mass in Buildings

While the concept of employing solar energy to heat Canadian buildings has considerable appeal, most solar energy systems tried in Canada are not cost competitive with conventional energy sources at present. This is particularly true in Alberta, where relatively low cost natural gas is widely used. Nevertheless, some researchers believe solar energy can make a significant impact on Canada's energy scene over the next 20 to 30 years if solar collectors and storage subsystems are integrated into the fabric, or structure, of buildings, thereby using the mass of each building as a heat storage and/or transfer medium.

To better understand the opportunities and limitations of "building-integrated" solar systems, a study was undertaken at the University of Calgary to determine the merits of several, generalized concepts.

Study Methodology

Of the various design options that could be incorporated into building-integrated concepts, cost considerations eliminated all but two from further consideration. The two preferred design options that were investigated in this study were: (1) direct gain, passive systems and (2) air-based, open circulation, active charge-passive discharge designs. In these two general configurations, integrated collection and storage systems function by (1) allowing the building structure itself to collect and store energy using only passive heat transfer processes, without the aid of mechanical systems or (2) using mechanical systems to transfer energy between the collector and storage subsystems. In this option, the storage subsystem is actively charged by a heat transfer fluid which has been warmed in active solar collectors.

To facilitate analysis of systems falling within these two classifications, numerical models were constructed to provide detailed information about short-term system behavior and to assess the sensitivity of storage systems to variations in design, the characteristics of the load and the energy input profile.

Numerical model development led to"ActPas", a combination of active and passive models which can be used as a design aid in making decisions about various building-integrated solar systems. Experience gained by other researchers while working with direct gain passive systems, and by investigators who worked with ActPas on this project, led to several, general design rules for both types of preferred system configurations. These "rules of thumb" provide an estimate of the key design values within which most well-designed systems should fall, as follows:

Rules of Thumb for Direct Gain Passive Systems

1. Storage Geometry:	
a. thickness	10 to 20 cm preferred; down to 5 cm acceptable with large surface area
b. surface area ..	3 to 4 times aperture
c. distribution	as evenly distributed as possible
d. orientation	vertical walls preferred; slabs must be directly exposed
2. Sizing Rules:	
a. aperture	1 m^2 per 800-1200 kJ/(°C·day) of load
b. storage capacity	800-1200 kJ/°C per m^2 of glazing

(Source: *Development of a Computer Program for Analysis of Thermal Mass in Buildings*, Byrne, Aidan P. and Tang G. Lee, September, 1986)

In a typical design exercise, the range of collector and storage sizes must first be estimated. Once the building load has been approximated, the rules of thumb can be used to produce a range of optional systems. From this information, a general outline of the building's orientation, mass, thermal storage requirements and collector type and area can be prepared. Then, ActPas can be used to obtain a preliminary cost-benefit analysis of the design options.

The ActPas computer model was used to design the solar storage wall used in the Sandstone Valley Ecumenical Centre, Calgary (under construction in 1986). Architects: Tang Lee and Richard Sandi.

Rules of Thumb for Actively Charged Building-Integrated Storage Systems[a]

	Wall	Slab
1. Storage Geometry:		
a. equivalent thickness (m)[b]	0.06-0.1	0.06-0.14
b. surface area[c]	2-4 times aperture preferred; 1-8 has significant benefit	2-4 times aperture preferred; 1-8 has significant benefit
2. Sizing Rules:		
a. collector aperture		
i) low As/Ac (e.g. 1)[d]	1 m^2 per 600-1200kJ/(°C·day) of load	1 m^2 per 900-1900kJ/(°C·day) of load
ii) high As/Ac (e.g. 4.8)	1 m^2 per 500-850kJ/(°C·day) of load	1 m^2 per 500-900kJ/(°C·day) of load
b. storage capacity[a]	250-750 kJ/(m^2·°C) collector	600-900kJ/(m^2·°C) collector

[a] Preliminary estimates only of the preferred range of active charge-passive discharge storage characteristics based on a limited analysis. Because system performance has been found to increase with storage capacity, generally the largest storage capacity available at the recommended thickness range should be used.

[b] storage volume/storage surface area

[c] both faces of walls are counted

[d] As/Ac = storage area/collector area

(Source: *Development of a Computer Program for Analysis of Thermal Mass in Buildings, Byrne, Aidan P. and Tang G. Lee, September, 1986)*

Results and Applications

Simulations showed that concrete block wall and standard floor slab active charge-passive discharge systems are comparable in terms of performance and are viable thermal storage methods. For wall systems, effective thicknesses of 0.06 to 0.08 metre (2.4 to 3.2 inches) are optimal, the thinner walls corresponding approximately to concrete blocks. For slabs, thicknesses of 0.06 to 0.14 metre (2.4 to 5.5 inches) are preferred.

Using ActPas, diurnal simulation can be used to observe the effects of design decisions on hourly energy flows and temperatures, under average meteorological conditions of passive, active charge-passive discharge and combined systems.

Also, ActPas simulations can be used to estimate the seasonal performance of these systems by simulating two- or three-day periods of each month of the heating season.

ActPas software, which is written for IBM-compatible microcomputers, is available at a nominal cost to cover materials and handling from the University of Calgary (see page 13). Researchers at the university have used the program to design a building-integrated solar system for a Calgary church.

Contacts

Details regarding studies at the Alberta Home Heating Research Facility are available from:

Dr. J.D. Dale
Department of Mechanical Engineering
University of Alberta
Edmonton, Alberta
T6G 2G8

Telephone: (403) 432-5317

For more information about Analysis of Thermal Mass in Buildings and access to the ActPas computer program, contact:

Tang G. Lee
Faculty of Environmental Design
University of Calgary
2500 University Drive, N.W.
Calgary, Alberta
T2N 1N4

Telephone: (403) 220-6608

Additional copies of this publication are available from:

Alberta Energy Information Centre
Main Floor, Bramalea Bldg.
9920 - 108 Street
Edmonton, Alberta
T5K 2M4

Telephone: (403) 427-3590

For more information about A/CERRF, contact:

Director, Energy Conservation
and Renewable Energy Research
Scientific and Engineering Services and Research Division
Alberta Energy
2nd Floor Pacific Plaza
10909 Jasper Avenue
Edmonton, Alberta
T5J 3M8

Telephone: (403) 427-8042

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